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Acoustic biotopes of intensive care units

How to listen and act effectively on the sounds of critical care with other listeners in mind

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Acoustic biotopes of intensive care units: How to listen and act effectively on the sounds of critical care with other listeners in mind

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The acoustic environment of an Intensive Care Unit (ICU) is a complex mixture of sounds ranging from medical alarms to mechanical ventilator hissing in the patient room or from conversations to trolleys rolling in the corridor. Some of these sounds play a crucial role in the medical practices of healthcare providers and some have impact on the wellbeing of the patients and families. However, the most fundamental aspect is that the ICU acoustic environment is shared by multiple listeners (e.g., nurses and intensivists, patients, families and visitors, physiotherapists, cleaning staff) each with different interests, needs and roles with respect to the sounds they hear and listen to. Our goal is to make intensivists and intensive care nurses more sound-conscious by informing them on intricate aspects of listening in the workplace, interacting with sound events and acting upon them. Drawing parallels from our earlier study on Operating Rooms (OR) [1], in this paper, we will reflect on listening to sounds in the ICU setting. Our approach is based on a literature review and knowledge developed by the authors based on years of research experience and publications in the critical care setting.

1. Background into fundamentals of environmental sounds

To understand how sound shapes the complex social and professional environment of the ICU, we must first establish a common vocabulary. This background section builds a conceptual framework, moving from the purely physical properties of sound and hearing to the crucial human elements of the soundscape approach and listening in action.

1.1. Sound and hearing

Sound is energy. Vibrations caused by moving objects (through air, water, or other flexible media) become sound when they reach the human hearing system. Hearing occurs when these vibrations cause auditory sensations and triggers sensory response (e.g., sharp, loud, rough). Source identification is not fundamental to hearing [2]. However, in the ICU, hearing quickly transitions to active listening as clinicians seek to identify the crucial sources of these sounds to be able to act upon them.

1.2. Types of sounds

We distinguish different types of sounds in our daily environment: **human sounds** (crowd, voices, physical impact), **natural sounds** (biological and geological phenomena such as animal voices/movement, weather events, water activity), **musical sounds** (vocal, electronic, instrumental either via distal or proximal interactions) and **technological sounds** (machines, electronics, alarm systems, vehicles underlying traffic or appliance noise). The perception of this mixture of sounds, i.e., how it is listened to and experienced, is what defines the soundscape.

1.3. Soundscapes and listening

Soundscape is 'the acoustic environment as perceived or

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experienced by people in context' [3] and can perceptually represent an entire collection of sounds in an acoustic environment (e.g., parks, hospitals, kitchens) [4]. The act of intentionally **'listening'** to the acoustic environment is fundamental for identifying sound sources in the soundscape. Listening guides the affective quality of how pleasant/eventful a soundscape is perceived. Accordingly, soundscapes can be described as *chaotic* (unpleasant and eventful), *vibrant* (pleasant and eventful), *calm* (pleasant and uneventful), and *monotonous* (unpleasant and uneventful). Listening is an individual experience. One listener's vibrant soundscape can be another's chaotic soundscape. Clinical soundscapes are increasingly a topic of interest not just because the complex mixture of alarms, talking, movement, equipment, and human activity requires detailed investigation; increasingly, artificial soundscapes (such as water, or birdsong) are being introduced into some patient areas because of their known healing properties [5,6]. Whilst a welcome development, the success of 'soundscapes within soundscapes' presents a further significant complication in the acoustic environment. Since the ICU soundscape is experienced differently by various individuals, it is essential to categorize the roles and attentive states of those listening within the environment.

1.4. Types of listeners

There is a range of active and passive listeners as a function of their attentive state and possibilities for action in an acoustic environment: these include **inactive listeners** (exposed to sounds), **passive listeners** (capturing sound events in the background), **active listeners** (in readiness to act), **sound users** (in search of a sound for a task) and **sound producers** (in action with the task causing sound). These distinct roles—from inactive patient to active sound user—are critical in our development of the acoustic biotope framework, which elevates the physical acoustic space to a concept of shared, interactive reality.

1.5. From acoustic space to acoustic biotopes

A biotope is a living environment co-habited by different species. An acoustic biotope then refers to a living/professional environment shared by different listeners [7]. However, there is a four-tier hierarchical structure between acoustic space (lowest level) and acoustic biotope (highest level). **Acoustic space** contains all possible sounds that are present in the biotope and is a physical representation of the sound events. **Acoustic environment** regards the situational/contextual occurrence of sound events which are relevant to listeners. **Bio-acoustic space** takes the listener and their hearing systems into account incorporating the notion of receiving and experiencing sounds. **Acoustic biotope** is an active and shared acoustic environment with complex interactions and sound-induced actions taking place in a specific space (e.g. an operating room) that has a well-defined function (surgical procedure) and hosts different types of listeners (a team of surgeon, nurses, and anesthesiologist and patient under surgery). To fully appreciate this complexity and the dynamics of listening, we must apply these concepts—listeners, sounds, and actions—directly to the shared acoustic environment of the ICU.

1.6. Sound-induced action in acoustic biotopes

In professional settings, listening is a basic skill needed to complete tasks and take required actions. Many operators are trained for using sound as a source of information and taking sound-induced action accordingly [8,9]. In the acoustic biotope of an orthopaedic OR, surgeons (as sound producer) use the tonal changes in the impact sound of hammering to ascertain the kneecap is in place; anesthesiologists (as sound users) monitor medical alarms to ensure patient safety; a sterile nurse (as active listener) purposefully follows the sounds of the surgery to provide surgical tools the surgeon; a circulating nurse (as passive listener) only reacts to dominant sound events in the background (e.g., falling tools, being called); and a patient (as inactive listener) is exposed to all sound events and has no control over the acoustic biotope (i.e., no observable sound-induced action). In acoustic biotopes, there might be an imbalance in the ability to act between inactive listeners (patients) and sound producers (surgeons) making some listeners more vulnerable to exposure to sounds and others more focused on the task and less on wellbeing. Such dynamics among listeners play an important role in why sound events need to be organised in an acoustic environment that is task-oriented yet appropriate for all. Thus, the notion of acoustic biotope incorporates different perspectives into listening practices and makes the physical acoustic space relevant for human condition and activities. We bring all these insights together to compose the basic components of an acoustic biotope fitting for ICU listening practices and experiences.

2. Acoustic biotope of intensive care units

The six fundamental aspects are detailed below to support different perspectives of listeners and their listening practices and experiences:

2.1. Listeners as actors in an acoustic space

We discern three different types of listeners with varying interests in the acoustic space of an ICU. Nurses, doctors, and other healthcare professionals interact with the environment, responding to alarms, sounds of patient monitoring and support equipment, and patients. They actively listen to the acoustic environment. Patients are inactive recipients of sounds experiencing mainly stress, anxiety, and lack of sleep being exposed to all sound events and often with little information regarding source sources. Families represent patient needs and listen to the environment with patients in mind and with concerns regarding patient safety.

2.2. Sound-producing events in the acoustic environment

The ICU is filled with diverse sounds—alarms, ventilators, monitors, conversations, and more. In general, the most dominant sounds are categorized as speech, alarms, human activity, and devices. These sounds compete for attention. Efficient organization of sound events within the ICU could enhance its overall functionality, ensuring that critical sounds are noticed without overshadowing others. If certain sounds need more attention, it would be a good practice to separate them from a hot spot of sound events to avoid masking effects. Moreover, it is important to note that sounds are interpreted differently by different listeners. On hearing the same alarm, a nurse may ignore a non-actionable alarm while a family may think the patient's condition is deteriorating.

2.3. Locals of sound and localizability in the acoustic environment

ICU patient rooms are occupied mainly by patients and their monitoring and support devices. The units may have an open plan in which all patients share the same acoustic environment or individual patient rooms, which defines the amount of sound exposure patients will receive. Auditory saliency becomes crucial, especially when localizing urgent alarms and other vital auditory cues from machinery and patient vocalizations. Healthcare professionals rely on habits and tacit knowledge when identifying sound sources and correctly acting on them. Thus, it is recommended to assign clear locations for receiving medical alarms (i.e., hand-held devices or nurse stations) or not to move around critical sound sources.

2.4. Listening capacity within the bio-acoustic space

Variability in individuals' hearing capacities is possible in the medical field, considering factors like hearing loss among healthcare professionals or desensitization to alarms. Similarly, the position of

professionals in the ICU, their specific roles, and their training contribute to increasing their listening capacity. Repetition of medical procedures enhances their ability to discern and respond to relevant sounds. Patients who are sedated, in comatose state and in sleep still have active hearing systems yet they may not be able to respond to sounds. Likewise, too much exposure to alarms may cause habituation among nurses and hinder critical sound-induced actions.

2.5. Common goal within the acoustic biotope

The ICU functions as a professional setting in which the healthcare team collaborates for the safety and well-being of patients. The acoustic environment becomes integral to their established routines and procedures. Strengthening the role of sound in these routines can contribute to more effective and comfortable workspaces hence better acoustic biotopes. However, the function of the ICU may also differ for different people or time of the day, or day of the week. Patients may interpret it as a healing environment, and weekends may offer more visiting possibilities. The experience of the soundscape is contextual: whether the ICU soundscape is chaotic or calm will depend on the function and the listeners. The clinical relevance of defining this common goal is that it provides a shared objective for organizing sound events to serve both effective care delivery and patient recovery.

2.6. Interactions with and via sounds in the acoustic biotope

In the ICU, interactions happen not only between healthcare professionals and equipment but also among team members. Sound serves as a tool for communication and coordination. Training healthcare professionals to use sound effectively can enhance their ability to navigate the acoustic biotope efficiently. Again, it is important to be aware and sound-conscious when engaging in activities that produce sound in order not to cause harm (e.g., sleep disruption caused by conversations) or annoyance (e.g., too many unactionable alarms caused by narrow alarm limits). Speech is an indispensable source of communication and is necessary. However, it is also the most prevalent sound source and should be reserved to specific locations or situations. A sound-conscious approach to these interactions is essential for mitigating alarm and noise fatigue in staff and reducing stress and fragmented sleep for patients.

These characteristics of the ICU acoustic biotopes, summarised in Fig. 1, allow us to have a comprehensive view of the relevance of sounds to a specific functional environment. Furthermore, the insights gained are relevant to ICU teams, patients and their families, clinical managers, designers for healthcare, clinical technologists, and policymakers who are active users of ICU soundscapes, affected by cacophony, or influential for structural change in healthcare. It becomes evident that the acoustic biotope of an ICU is a dynamic and shared environment in which healthcare professionals work collectively and individually toward the common goal of patient care. Understanding the nuances of sound within this context can lead to improvements in both the work environment and patient outcomes.

3. Practical tips for optimizing the ICU acoustic biotope

Drawing upon the principles of the acoustic biotope framework, and using our past experiences and studies in this field, we propose several practical tips that ICU teams can implement immediately to create a more functional and less harmful environment for both staff and patients:

1. **Define and communicate the shared mission for your unit:** Clearly articulate to all staff and families that the collective mission is **patient recovery through controlled sound-induced action**. This shared understanding justifies why certain alarms must remain audible (to support clinical action) while simultaneously enforcing noise reduction measures (to support patient rest). [10,11]
2. **Implement role-based sound protocols:** Recognize that **listening is an individual, role-dependent experience**. Assign specific "Sound Users" (e.g., the primary nurse) who are responsible for responding to the immediate device alarms. This defines the **dynamics of attention** and prevents all staff from becoming passive listeners habituated to all sounds as is the case with alarm fatigue. [12,13]
3. **Establish 'quiet locals' and task zoning:** Identify areas (locals of sound) where tasks concentrate, resulting in high intensity. Establish quiet habits in certain areas (e.g., a documentation or remote charting zone, or patient sleep area) and strictly enforce silence policies there, acknowledging that noise concentrates where team interaction is high. [14,15]
4. **Manage loudest harmful sources (speech and equipment):** Since **verbal communication** is often the **loudest** perceived sound source, strictly enforce the "huddle voice" policy—keeping conversations low, targeted, and away from patient bedsides, especially at night. For loud equipment or necessary procedures, coordinate use during minimal patient rest periods to reduce harmful exposure to inactive listeners. [1,16]
5. **Optimize interaction via targeted sound:** Leverage sound tools to facilitate interactions without broadcasting noise. Utilize **targeted communication** (e.g., handheld devices or pagers) for team member interactions, ensuring alerts and communication are direct and limited to the relevant recipients, thereby minimizing unnecessary acoustic disruption in the shared biotope. [12,13,17] In tenders, demand that, where possible, alarms are easy to learn and distinguish between, as well as easily localizable and compliant with the updated global medical device standard (IEC [18]). [19,20–22,23]
6. **Increase opportunities for patient action (Inactive Listeners):** Though patients are primarily inactive listeners, try to offer small opportunities for sound control where safe. Simple measures, such as offering noise-canceling headphones during non-critical periods or providing clear information about the *meaning* of non-actionable sounds, can reduce the stress associated with being a vulnerable

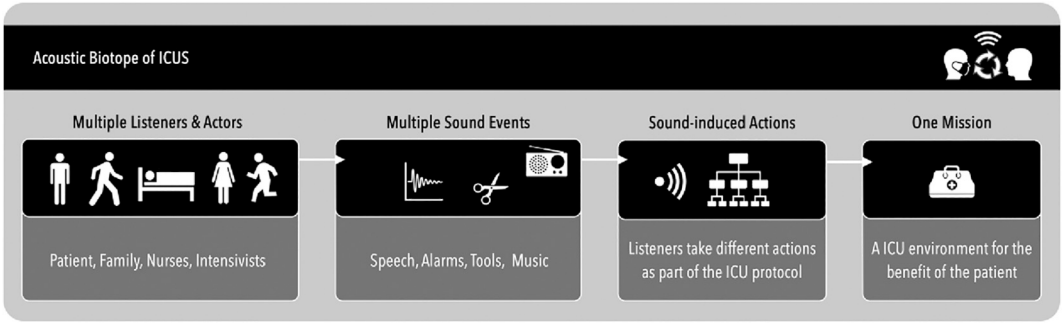

Fig. 1. Main properties of sound-induced action in the ICU Acoustic Biotopes.

recipient of acoustic events. In addition, consider introducing positive sounds (e.g., birdsong, nature sounds, or music selected by patients and family) to stimulate or comfort patients. [24,25,26]

4. Clinical implications of the acoustic bitope framework

Understanding the nuances of sound within this context can lead to strategic improvements in both the work environment and patient outcomes [27]. The **Acoustic Biotope of the ICU** framework offers intensivists and nurses a new lens through which to view, inspect, and act upon sound. This lens translates directly into actionable steps for achieving a better, safer, and more restorative critical care environment:

- **Training and Sound-Consciousness:** Explicitly incorporating sound management into clinical training to enhance staff's ability to discern and respond to relevant sounds and become effective sound users (Tips 2 & 5).
- **Systemic Organization:** Advocating for institutional changes to the physical and technical environments, such as assigning clear locations for receiving alarms, strategically separating sound events to avoid masking critical cues, and offer positive sounds (Tips 1, 3, & 5)
- **Balancing the Biotope:** Actively working to reduce the vulnerability of inactive listeners (patients) by being sound-conscious in activities like conversation and alarm management. This is a move toward an acoustic environment that is task-oriented yet fair for all listeners (Tips 4 & 6).

By adopting the acoustic biotope framework, clinical teams and policymakers can move beyond simply measuring decibels to **actively listening and acting effectively** on the sounds of critical care relying on their own experiences with ICU sounds, as it has been demostrated that more positive soundscapes have positive physiological and psychological effects on listeners [28].

CRediT authorship contribution statement

Elif Özcan: Writing – original draft, Visualization, Resources, Methodology, Formal analysis, Conceptualization. **Judy Edworthy:** Writing – review & editing, Resources, Conceptualization.

Declaration of competing interest

We declare no conflict of interest in the making of this manuscript and the research behind it.

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